EARTH'S ALBEDO SYMMETRY AND CLOUDINESS

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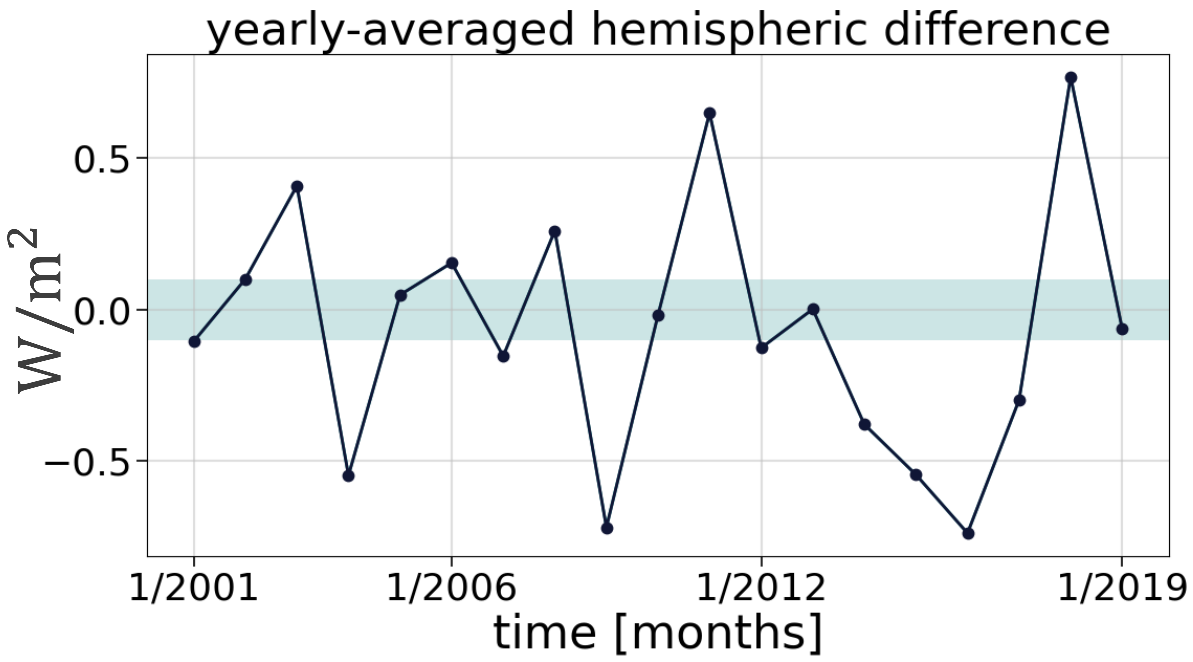
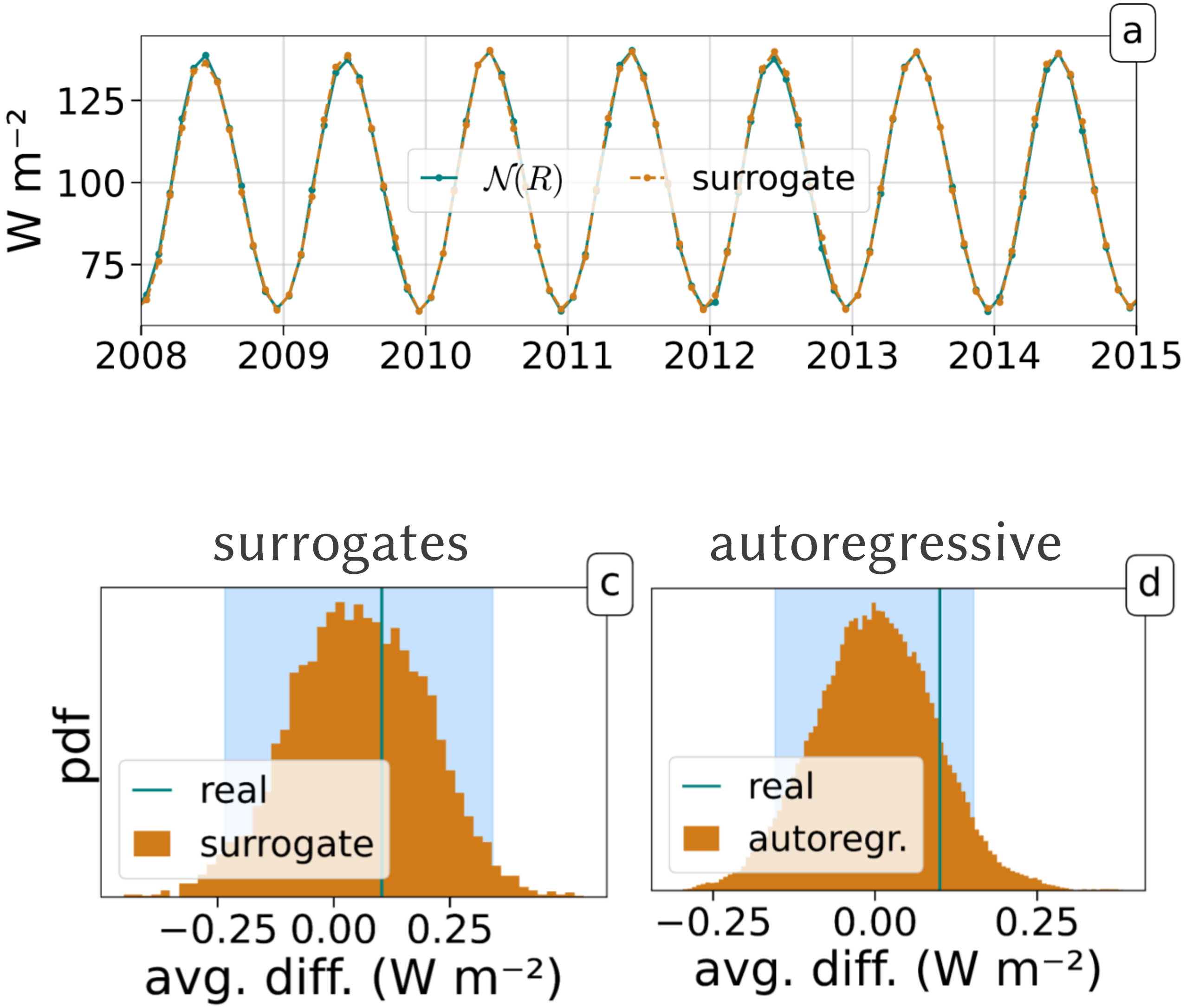
- CERES → all-sky reflected solar irradiance R → **hemispheric symmetry of R**
  - $\delta R \equiv$ hemisph. diff. $\approx 0.1\ \mathrm{W/m^2}$ (20-year-mean)
  - 0.1% of global mean, vs. 6% asymmetry in clear-sky
  - This "symmetry" is "known" for a long time (*)
  - Exists because clouds compensate surface asymmetries. Don't know how or why...



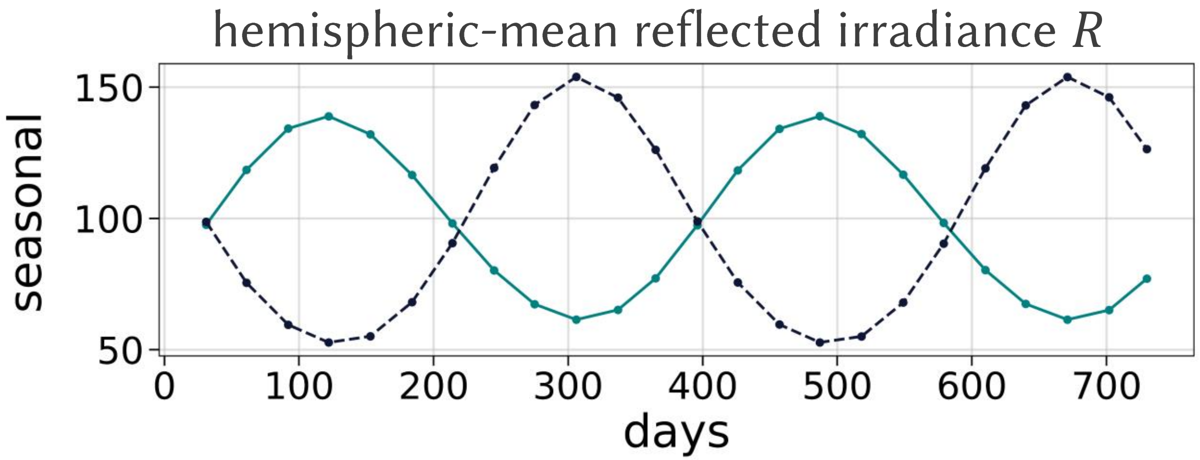
- Why is this interesting?
  - Is it by chance, or some interesting physics?
  - Why do the models fail to capture this robust effect?

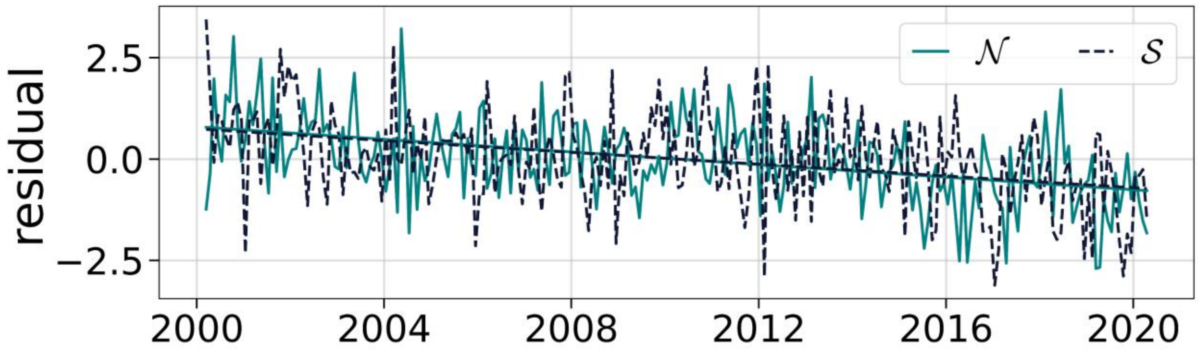
(*) *E.g. Ramanathan et al 1987-9, Stevens & Schwartz 2012, Voigt et al 2013, Stephens et al 2015*

- How significant is the value of $\delta R = 0.1\ \mathrm{W/m^2}$?
  - We showed, via two different techniques, that δR is statistically indistinguishable from 0
- **Timeseries surrogates,** standard nonlinear timeseries analysis technique
  - Fake timeseries which have same periodic structure as real signal, but keep no correlations between different cycles
  - Simulate thousands of surrogates; what's the distribution of their time-averaged hemispheric difference?
- A different analysis (autoregressive modelling, backup slides), provides yet another distribution
- δR is **indistinguishable from 0**
- **Margins of error** of $\delta R \approx 0.28\ \mathrm{W/m^2}$

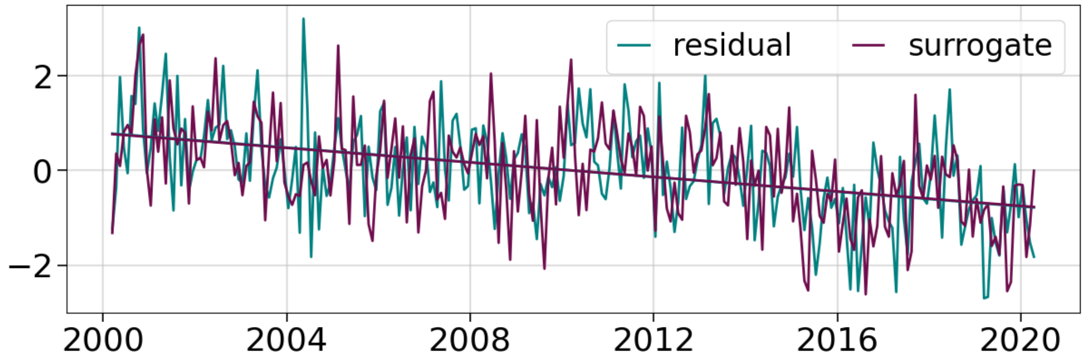


- *If there is a mechanism that establishes symmetry*, where could we see it?
  - Perhaps fluctuations in residuals R'_S drive R'_N or vice versa → analyze residuals



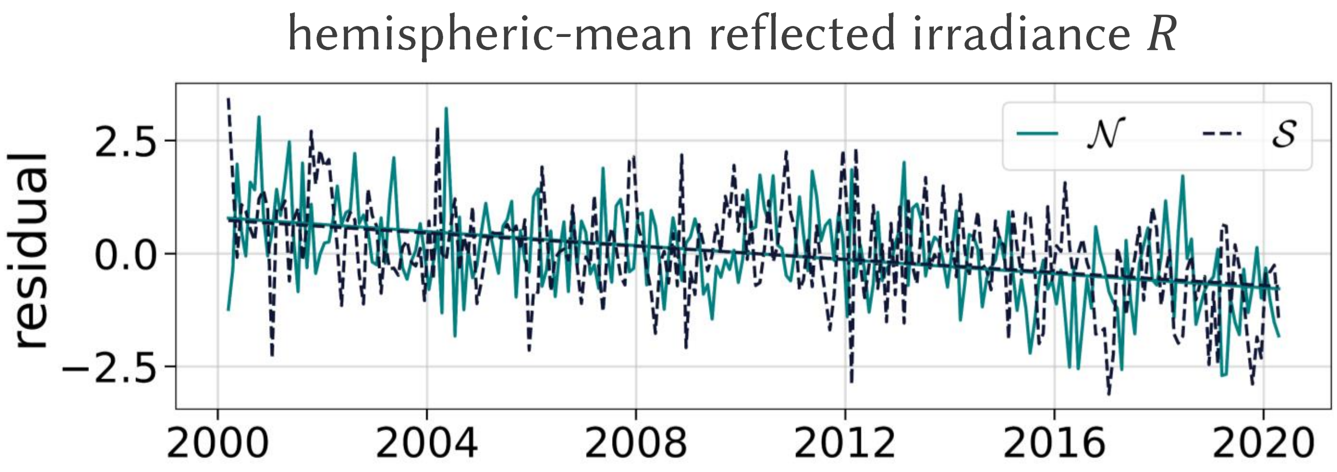


- Seasonal cycle (6 & 12 months) contains **overwhelming (99%)** amount of R variability
- Residuals of R are indistinguishable from **Gaussian noise** with superimposed trend
- Shown via the method of surrogates (and others)



- **Thus, residuals evolve independently, at least at the yearly & sub-yearly timescale!**

- **Residuals = noise → no** indication of **dynamical connection** between the hemispheres…



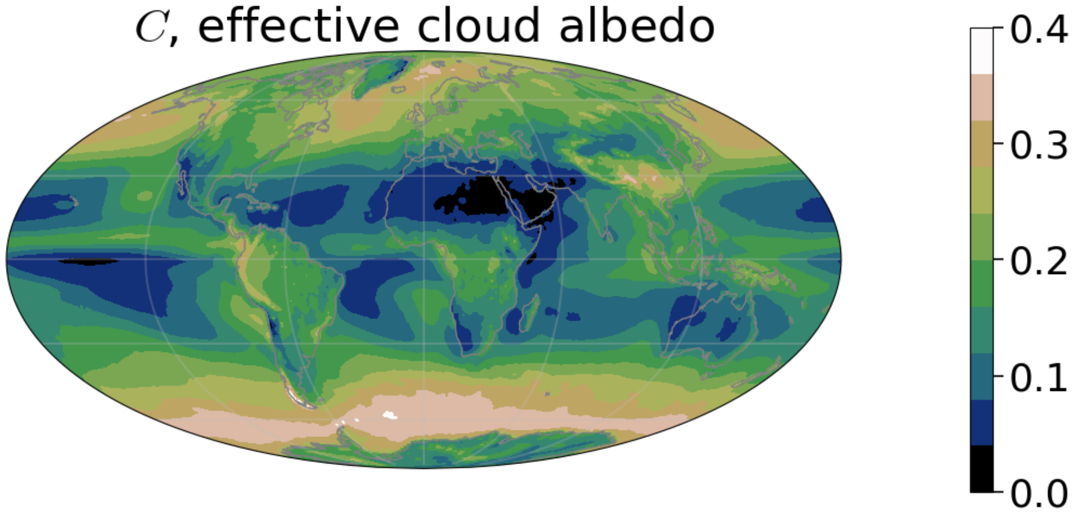
- **But**, both residuals share **identical decadal** trends of ≈0.7 W/m^2/decade!
  - Loeb et al. (2020) attributed the trend to north-eastern Pacific stratocumulus forced by decadal variations in sea-surface temperatures.
  - Why is a trend in NH, attributed to mostly localized changes, is so well mirrored a SH trend?
  - The trend by itself favors the existence of a communication mechanism at longer timescales

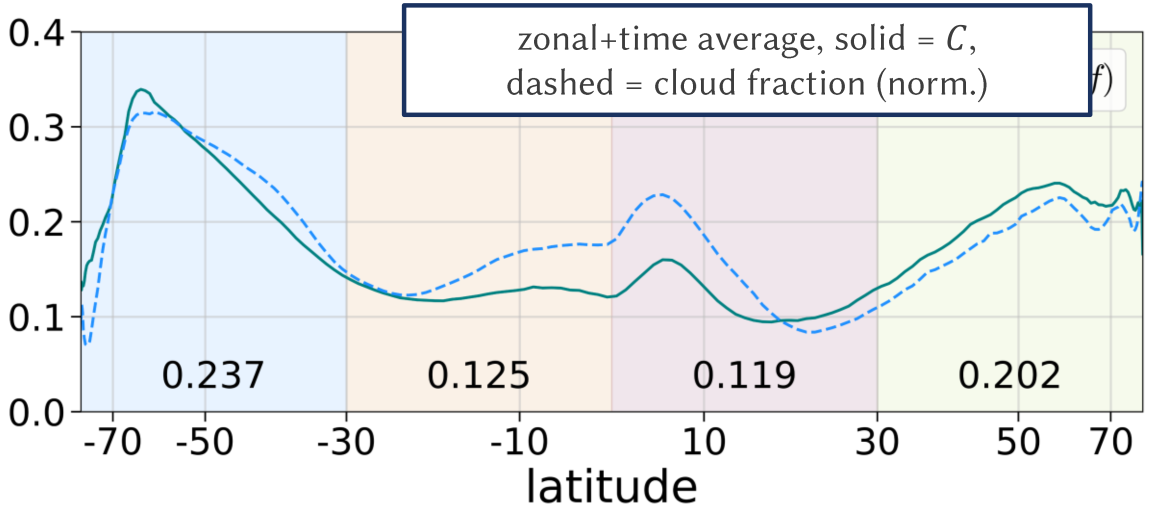
- Clouds compensate → analyze their albedo!
- Cloud albedo based on a parameterization [1]

$$C = f\,\frac{\sqrt{3}(1-g)\tau}{2+\sqrt{3}(1-g)\tau}$$

f = cloud area fraction, τ = cloud optical depth
g = asymmetry factor of cloud particle phase function

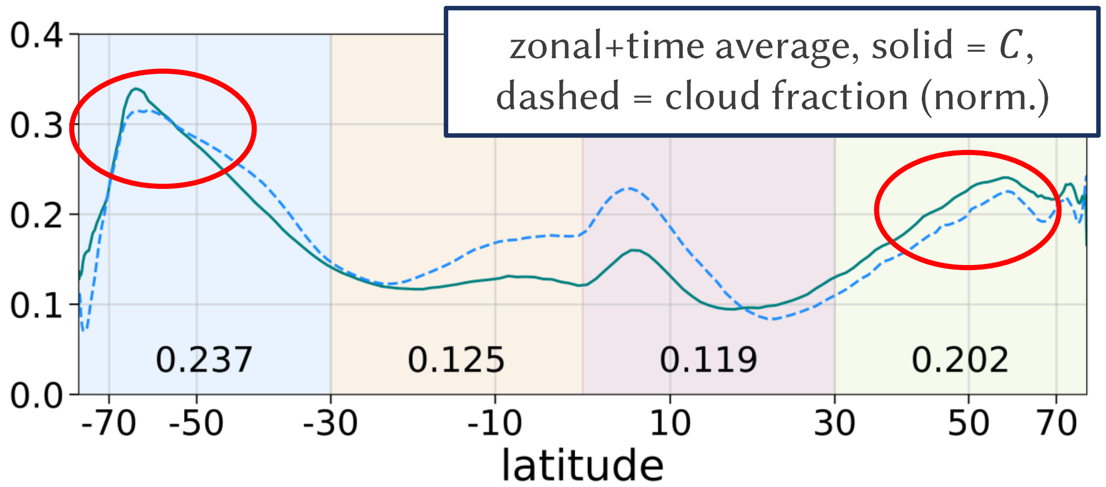
- This formula is further calibrated so that adding C to clear-sky albedo results in an energetically consistent total albedo
  - (more in backup slides)

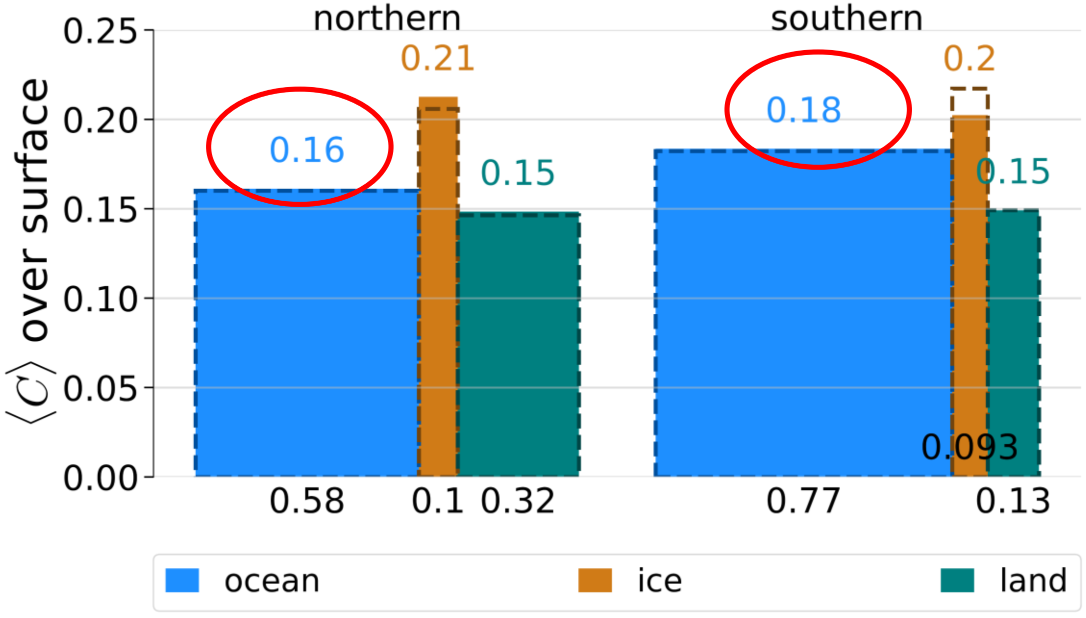




[1] Lacis & Hansen (1974). *A Parameterization for the Absorption of Solar Radiation in the Earth's Atmosphere.* Parameterizations are fitted to multiple-scattering detailed numerics. Setup is plane-parallel & two-stream approximation. Further approximations leading to the above formula: (1) the lower atmosphere is primarily a scattering region with negligible absorption (2) Rayleigh scattering is neglected.

- Hemispheric difference of cloud albedo is $\delta C \approx -0.02$
  - This captures most of the clear-sky albedo difference which is ≈ 0.02
  - Where is the C asymmetry coming from?
- Ocean is cloudier than land *and* SH has more ocean: can explain at most 19% of δC
- Tropics contribute ≈15% of δC
- Remaining: strong asymmetry of C **of extratropical ocean storm tracks!**
  - SH storm tracks have much higher cloud albedo





THE SITUATION IS PERHAPS EVEN MORE PUZZLING…

- We did **not** find a communication mechanism, **nor** proven one exists guaranteed!
- Here is the gist of the matter:
  - Let's say there is a communication mechanism. If true, the residuals wouldn't be noise, unless the mechanism operates at much longer timescales…
  - If it happens at ultra long timescales, this doesn't explain why the trends follow each other (short timescale of 10-20 years)…
  - If it were chance, it would have to explain both mean and trends being hemispherically symmetric
  - Extra-tropical cloud imbalance = reason for symmetry: forbids shift of ITCZ as mechanism, hints at long timescales affecting SST patterns and cloudiness at the largest scales
  - Perhaps CERES processing brings symmetry? Unlikely, other rad. measurements capture symmetry
- What's the deal with models?
  - Models do not reproduce the symmetry, nowhere near the reported margins of 0.28 W/m^2
  - They should though! They are already asked for dW/m^2 differences w.r.t. warming…
  - If they do capture it, do they do it correctly (extra-tropical storm tracks imbalance)?

THANK YOU! QUESTIONS?

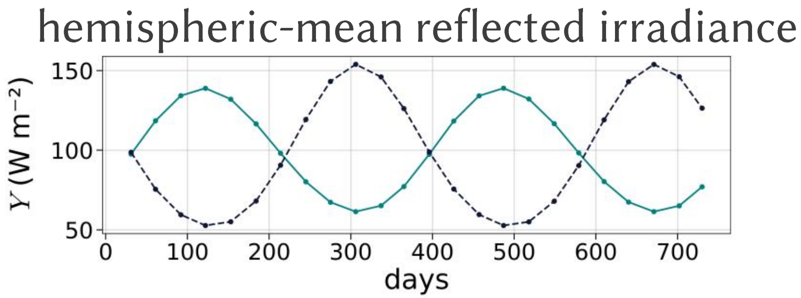
Preprint: doi.org/10.1002/essoar.10506526.1
(version 2 coming soon!)

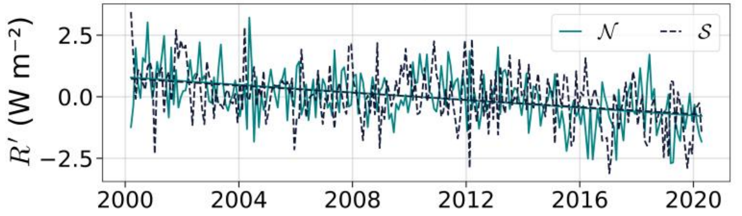
Open source (and easy to use!) software for surrogate timeseries analysis: TimeseriesSurrogates.jl

APPENDICES

From satellite radiation measurements we analyzed Earth's albedo:

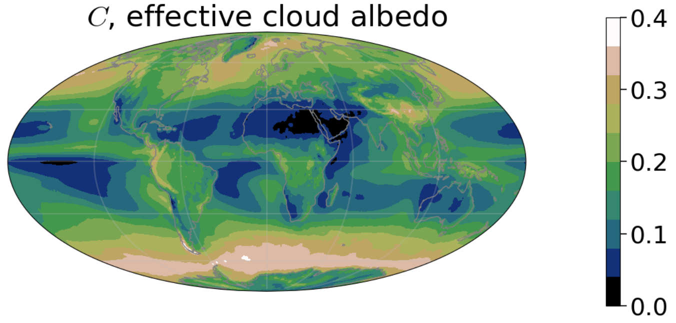
- ❑ Earth's TOA albedo is hemispherically symmetric over long time-averages, established with two different methods
- ❑ Residuals of reflected solar irradiance are indistinguishable from Gaussian noise and do not indicate dynamics that establish hemispheric symmetry in yearly timescales…
- ❑ …but, residuals of both hemispheres share identical decadal trends, which, while unexplained, suggest the existence of a symmetry-establishing mechanism at longer timescales

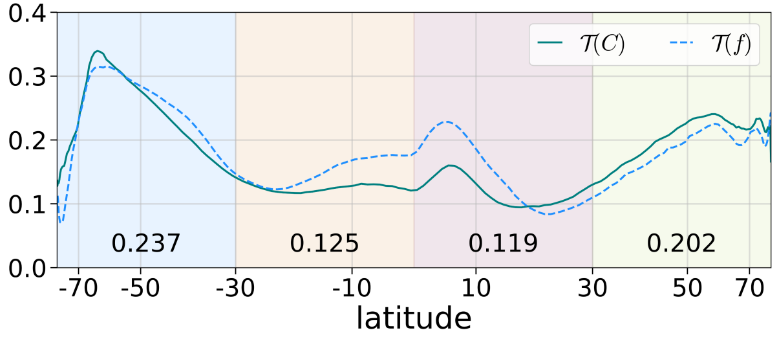




Using cloud properties measurements we analyzed cloud albedo:

- ❑ We created an energetically consistent cloud albedo field C
- ❑ Hemispheric clear-sky albedo asymmetries are balanced mostly by hemispheric asymmetries in extra-tropical storm-track cloudiness





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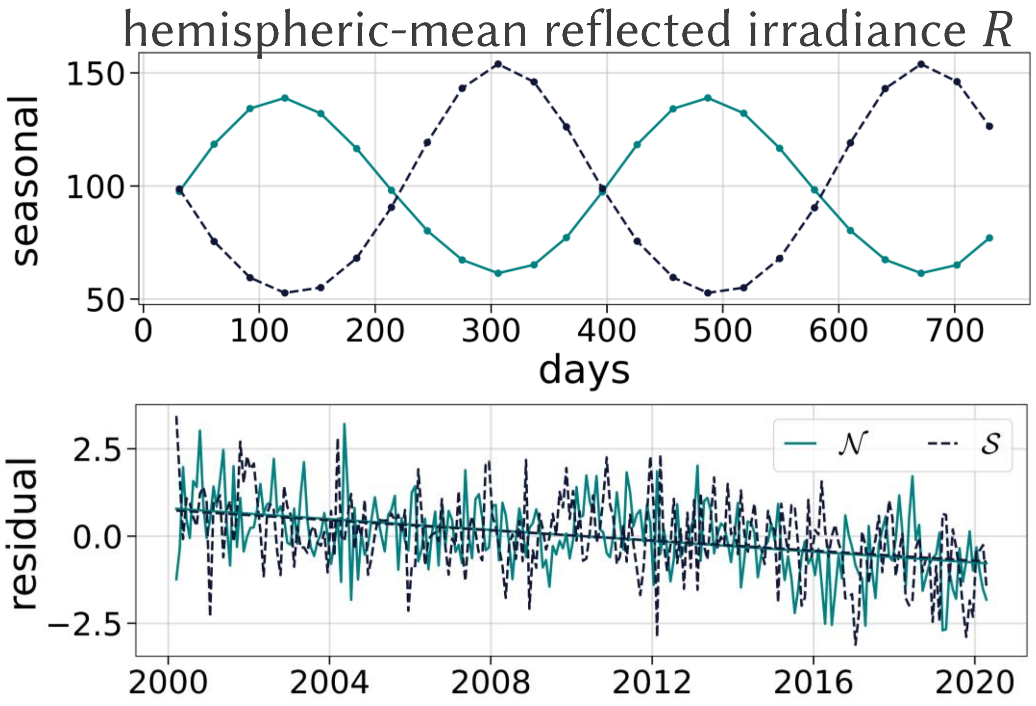
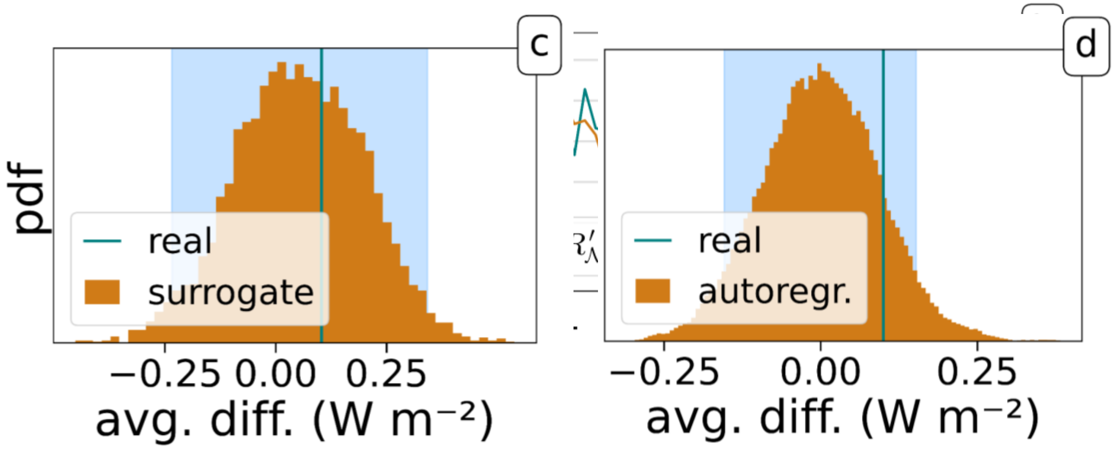
- Let's now get rid of the seasonal cycle. Decompose hemispherically averaged R_N or R_S to:
  - seasonal component Y (only has 12 & 6 month Fourier components, and average value of R)
  - residual (a.k.a. anomaly) component R'
- What if the observed asymmetry of 0.1 is a result of finite-time sampling (20 years) of fluctuations?
- **Autoregressive modelling**. Hemispheric difference of residual timeseries is approximated as

$$D_t = \sum_{i=1}^{12} \theta_i D_{t-i} + \eta_t, \qquad \eta_t = \text{white noise}$$

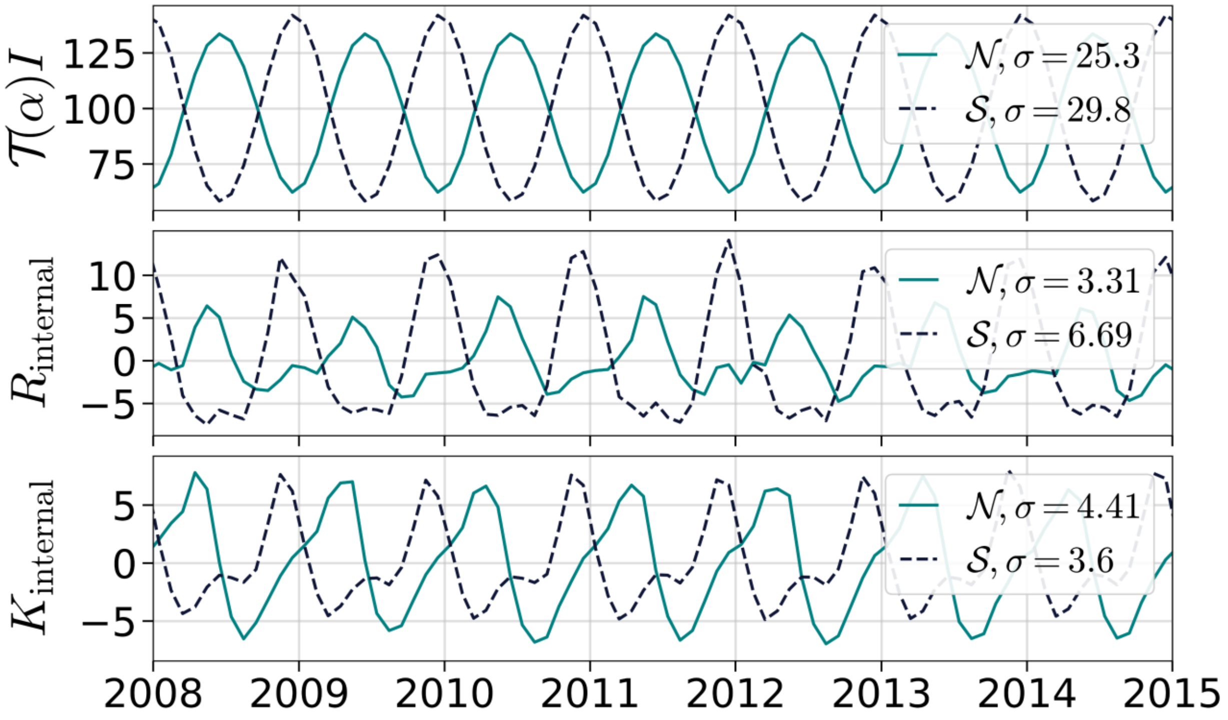
- Simulate infinitely long D_t. If we subsample 240 months, what possible means should we expect?
- Hemispheric difference is **indistinguishable from 0**
- **Margins of error of asymmetry ≈ 0.28 W/m²**





- Our seasonal decomposition removes seasonal fluctuations of R that are both due to insolation as well as physical albedo seasonal fluctuations (e.g. ice melting)

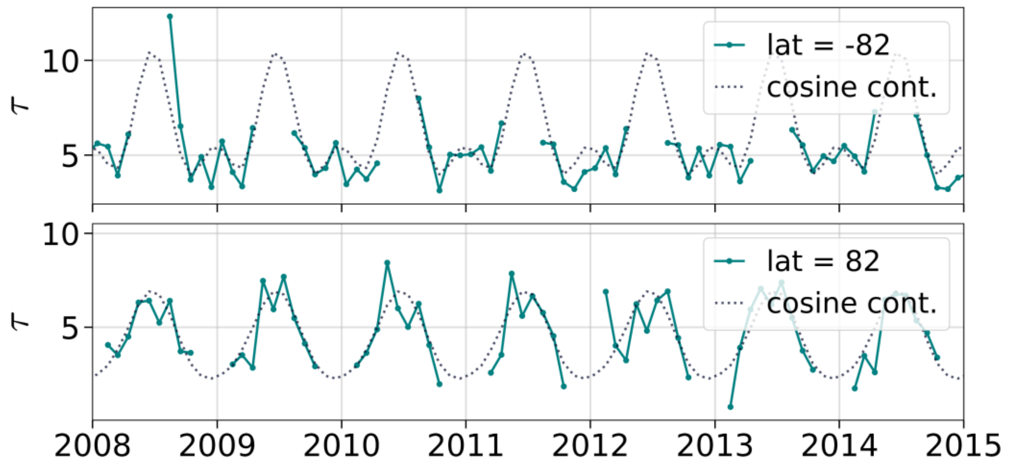
- **Mean albedo decomposition**
  - Let $T(a)$ = temporally averaged albedo
  - Then $T(a)I$ is the fluctuations due to I
  - $R_{internal} = R - T(a)I$ are all internal fluctuations, seasonal or not

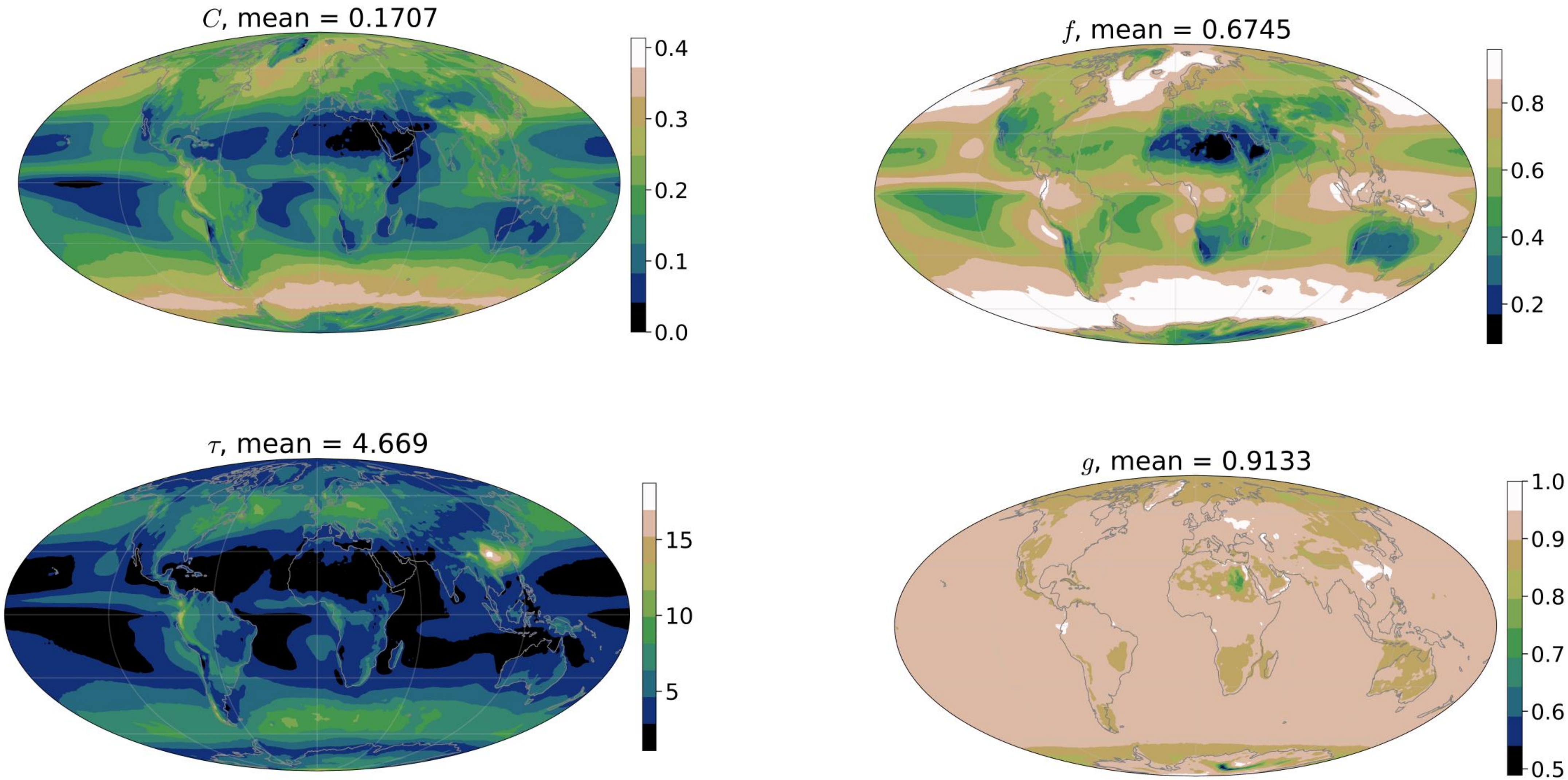


- Variability of R attribution:
  - NH: 84% from $T(a)I$, 1% from $R_{internal}$, 13% from co-variability of $T(a)I$ and $R_{internal}$
  - NH: 68% from $T(a)I$, 3% from $R_{internal}$, 28% from co-variability of $T(a)I$ and $R_{internal}$

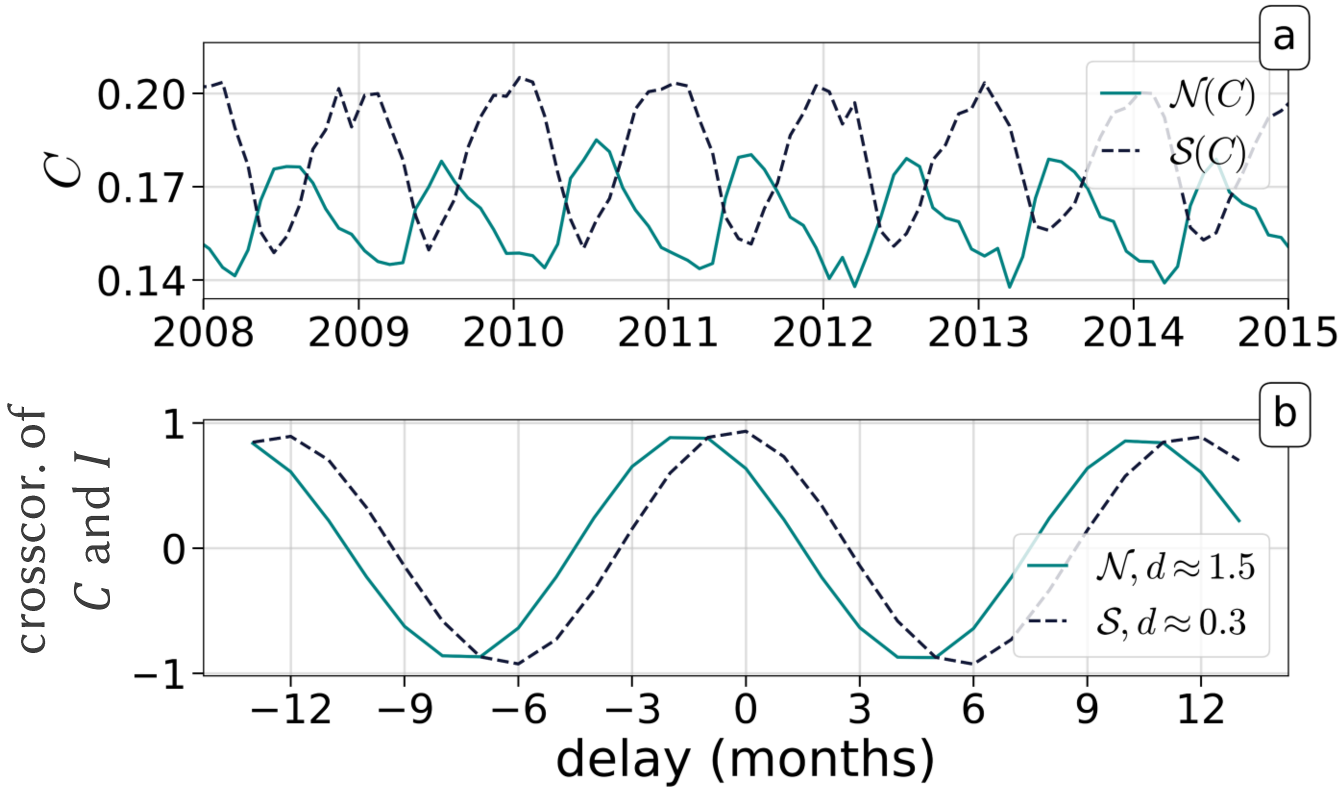
- So once again, most of the variability comes from the insolation

- Donohoe & Battisti 2011: decomposition of TOA albedo to atmosphere and surface contributions
- $a^{ATM} = \frac{a - a_s t^2}{1-(a_s t)^2}$, $a^{SFC} = a_s t^2(1 - a\, a_s)$, $a = \frac{F_\uparrow^{TOA}}{F_\downarrow^{TOA}}$, $t = \frac{F_\downarrow^{SFC}}{F_\downarrow^{TOA}}$, $a_s = \frac{F_\uparrow^{SFC}}{F_\downarrow^{SFC}}$ $\Rightarrow$ $a = a^{ATM} + a^{SFC}$
- We do this decomposition for both all- and clear- sky. Then $a^{CLD} = a^{ATM} - a^{ATM}_{clear}$
- We use a^{CLD} to energy-calibrate our albedo: $C = f\frac{\sqrt{3}(1-g)\tau}{2+\sqrt{3}(1-g)\tau}$
- CERES provides f, τ. τ has missing values → normalized
- g has to estimated, and can be taken as ≈ 0.9, BUT, choosing g to vary spatially so that timemean of C is the same as timemean of a^{CLD} gives us an energetically consistent C.




C, mean = 0.1707
0.0
0.1
0.2
0.3
0.4
f, mean = 0.6745
0.2
0.4
0.6
0.8
τ, mean = 4.669
5
10
15
g, mean = 0.9133
0.5
0.6
0.7
0.8
0.9
1.0

- $R = a\, I$. So for the value of R the **covariability of albedo and insolation matter!**
- Plot (a): hemispherically-averaged timeseries of cloud albedo C
- Plot (b): cross-correlation function of C with insolation I. The peak of the cross-correlation is d
- It shows that peak cloudiness lags behind solar peak for 1.5 months in the NH and for only 0.3 in the SH
- Thus, SH is **cloudier when it is sunnier!**



- This accounts for about 10% of the compensation of clear-sky asymmetry by clouds, see paper online for technical details

- Plots from ongoing work of Traute Crueger (MPI-MET) on the representation of albedo symmetry on CMIP models

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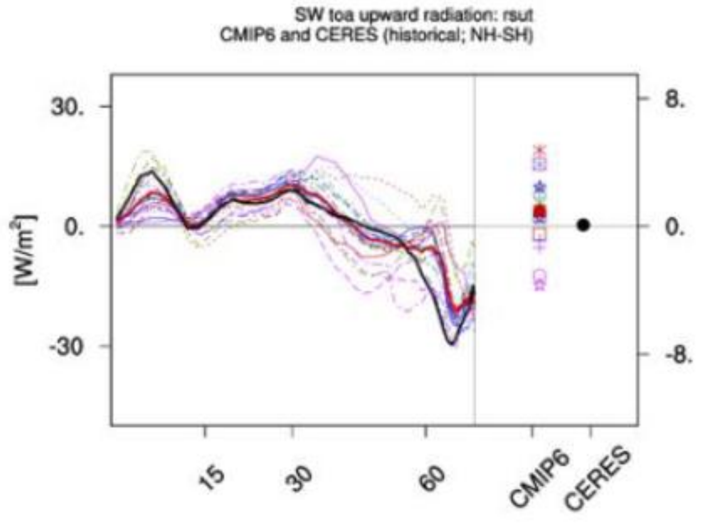
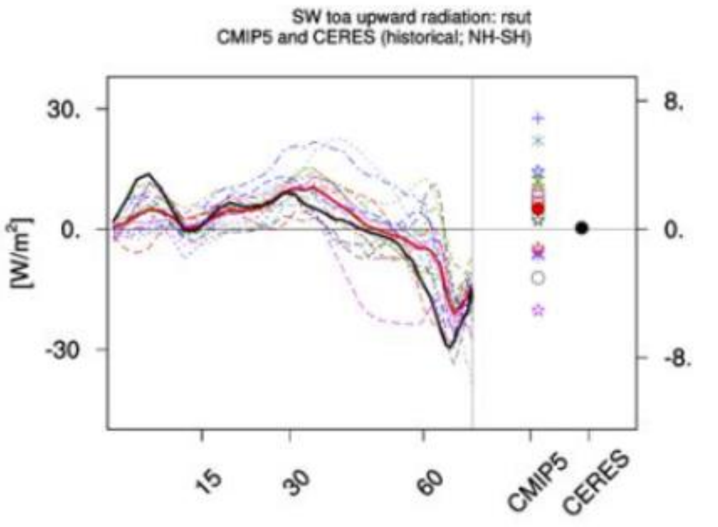
<tr><td>ΔR_{all}</td><td>
</td><td>
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- Models are nowhere near the margins of error we have established $\pm 0.3\ \mathrm{W/m^2}$